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Allometric equation for aboveground biomass estimation of *Galiniera saxifraga* (Hochst.) Bridson in Gesha-Sayilem forest, southwestern Ethiopia

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Abstract. *Bareke T, Addi A. 2021. Allometric equation for aboveground biomass estimation of* Galiniera saxifraga *(Hochst.) Bridson in Gesha-Sayilem forest, southwestern Ethiopia. Asian J For 5: 76-82.* There is limited information about the precise quantification of Aboveground Biomass (AGB) of species-specific allometric equations for shrubs and small trees. Thirty *Galiniera saxifraga* plants were selected to develop species-specific allometric biomass equations. Biometric parameters, including the diameter at the Breast Height (DBH), height and crown area were predictive variables that were measured for each individual plant. AGB was measured through a destructive method. The AGB was correlated to biometric variables using regression analysis. The species-specific allometric models, with DBH and crown area as predictors (DBH-crown area models), accounted for 90% of the variation in the AGB of *G. saxifraga*. The DBH-crown area model was adequate for predicting the AGB for *G. saxifraga* with the adjusted R^2 value 0.9 and AIC values was 47.37. The specific allometric equation developed for the Gesha-Sayilem Afromontane forest can be used in similar moist forests in Ethiopia to implement Reduced Emission from Deforestation and Degradation ($REDD^+$) activities to benefit the local communities from carbon trade.

Keywords: Allometric equation, aboveground biomass, biometric variables, Gesha and Sayilem

INTRODUCTION

Galiniera saxifraga (Hochst.) Bridson is a shrub up to 4 m high and sometimes up to 10 m high. Its' branches grow out in whorls from the trunk hanging down with regular rows of large opposite leaves. Leaves shiny, ovate, the tip clearly pointed with a hairy stalk. Flowers are small, white and fragrant like coffee flowers, fruit a green berry, which is ripening red. The species can be propagated from seeds and seedlings. It is common to plant species growing in a wide range of habitats, commonly growing in upland forest but sometimes also in secondary montane scrub, often near streams at altitudes between 1500 and 3000 m in most floristic regions of Ethiopia, and also in Eritrea and south to Zambia and Malawi (Addi et al. 2014).

The fragrance of the flowers attracts honeybees for nectar and pollen. It is one of the major honey source plants during September, October, and November in Gesha-Sayilem forest southwest Ethiopia (Bareke and Addi 2020). It contributes to honey production in association with other plants. The plant is also used for firewood, farm tools and the fruit is used as shot by children to make the sound of gun. *G. saxifraga* is one of the dominant shrub species in sub-canopy of Gesha-Sayilem forest. Gesha-Sayilem forest is designated as part of Bonga National Forest Priority Area and it is found under good conservation. All plant species which are found in this forest are under good conservation status including, *G. saxifraga*.

Forest ecosystem is a major component of the carbon reserves and it plays an important role in moderating global climate change through process of carbon sequestration (Addi et al. 2019; Tadesse et al. 2019). Tropical forest is a major component of terrestrial carbon cycle and it has a great potential for carbon sequestration, accounting for 26% carbon pool in aboveground biomass and soils. Biomass estimation of tropical forests is crucial for understanding the role of terrestrial ecosystems to the carbon cycle and climate change mitigation. This is very important for decision support in forest management, for monitoring forest conditions, and to know changes in carbon stock as required in the emerging Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD+) mechanism (Brassard et al. 2009; Ali et al. 2015; Ancelm et al. 2016). Under the United Nations Framework Convention on Climate Change (UNFCCC), countries have to report regularly the state of their forest resources through assessments of carbon stocks based on forest inventory data and allometric equations (Preece et al. 2012; Makungwa et al. 2013). In forest ecosystems, the aboveground biomass (AGB) of shrubs and small trees comprises an essential component of total forest biomass. However, due to limiting the accurate quantification of aboveground biomass in both shrubby vegetation and forests, species-specific allometric equations for shrubs and small trees are relatively scarce (Cavanaugh et al. 2014; Ali et al. 2015).

The allometric equation, estimates the whole or partial mass of a plant species from measurable tree dimensions, including trunk diameter, height, wood density, crown area, or their combination (Kuyah et al. 2012; Tadese et al.

2019). The most common allometric model used to predict biomass is the power function Y = a × Xb, where Y, dry biomass weight, a is the integration factor, b is the scaling factor, and X is the diameter at breast height (Djomo et al. 2010). This function is considered the best applicable mathematical model for biomass studies because the growing plants maintain the different mass proportions between different parts. Allometric biomass equations have been developed for tree species in different ecological regions of the world, which are related to species-specific and strand-specific biomass models (Rebeiro et al. 2011).

The biomass models for moist Afromontane forest species of southwest Ethiopia are valuable tools for the estimation of carbon stocks in mitigation of climate change. The largest carbon pool is reserved in the aboveground living biomass of the trees or shrubs and it is the most directly impacted by deforestation and degradation. Different authors have attempted to generate biomass equations for tropical forests for the estimation of aboveground biomass (Henry et al. 2011; Chave et al. 2014; Edae and Soromessa 2019) and these equations may not accurately be revealed the tree biomass in a specific region due to variability in wood density and the architecture of trees among and within species. Allometric equations which are regressions linking the biomass to some biometric variables such as diameter, height, and wood density are used to estimate tree components from the forest (Adrien et al. 2017; Altanzagas et al. 2019). However, in tropical forests, accurate estimates of carbon sequestration are lacking due to a scarcity of appropriate allometric models. The generic equation developed by Chave et al. (2005) may not adequately reveal the trees or shrubs biomass in a specific region in tropics including Ethiopia.

Therefore, species-specific equations are important to achieve higher levels of accuracy because trees of different species may differ greatly in tree architecture and wood density. The study area is part of the tropical forest. No study was conducted to develop species-specific allometric equations to estimate the biomass for mitigating climate change effects, specifically developed for shrubs (Conti et al. 2013; Nogueira et al. 2018). Current strategy of reducing emission from deforestation and forest degradation mechanism for conservation of forest carbon requires a precise and verifiable estimate as a principal point for monitoring. Thus, the accurate estimation of forest carbon is important to evaluate if the designed policies mitigate carbon dioxide emission (Henry et al. 2013). The mutual tactic of quantifying carbon stock in a forest is through application of reliable allometric equations for AGB estimation (van Breugel et al. 2011).

Thus, the aim of this study was to estimate aboveground biomass of the *G. saxifraga* in order to develop species-specific allometric equations that could be used for biomass and carbon stock estimation in moist Afromontane forest of southwest Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study area is located in the Southern Nations Nationalities Peoples Regional State (SNNPRS), in Kaffa Zone at Gesha and Sayilem districts of Ethiopia. It is located between 6^0 24’ to 7^0 70’ North and 35^0 69’ to $36^0$78’ East (Figure 1). The topography of the landscape is undulating, with valleys and rolling plateaus and some areas with flat in the plateaus. The altitude ranges from 1,600m to 3000m (Addi et al. 2020). The monthly mean maximum and minimum temperature for Gesha are 29.5 ^{0}C and 9.5 ^{0}C, respectively. On the other hand, the monthly maximum and minimum temperatures for Sayilem range 10^{o}C to 25^{o}C, and the annual rainfall for both districts range 1853-2004 mm.

Sampling design

A reconnaissance survey was carried out for the purpose of getting the overall impression of physiognomy of the forest, select sampling sites, and accessibility. This helped to design the data collection methods prior to actual data collection. Because of the rugged and undulating nature of the topography of the area and its inaccessibility, collection of representative vegetation data using systematic sampling methods was not feasible, and therefore stratified random sampling methods were employed to collect vegetation data. For this purpose, altitudinal stratification was taken as criterion to divide the study area into different strata in order to get homogenous sampling units. Based on stratification principles, therefore the study area was divided into five elevational strata and the elevation distribution was extracted from the Digital elevation model (DEM) as indicated below starting from the lower to the highest altitude at intervals of 200m (Figure 2).

Species sampling

A direct destructive sampling method was applied for AGB measurements of individual trees. After measurements of shrub DBH and crown area, the plants were cut and the height of the felled plants was measured. The individual plants were partitioned into three components namely, stem, branches, and leaves (including twigs with leaves having < 1 cm diameter). Six individual plants were randomly taken from each altitudinal strata to cover the widest possible range of plant sizes observed in the forest. A total of 30 individual plants were taken from the whole forest for AGB determination following methods developed by Maraseni et al. (2005) and Picard et al. (2012). Keeping climatic and soil conditions as constant as possible, the selected species were sampled across the study area.

Prior to destructive sampling, total height (H, meter), defined as the distance between the ground surface and the highest crown point; diameter at breast height (DBH, centimeter), maximum crown diameter (CD1, meter), and its perpendicular diameter (CD2, meter). Crown diameters were used to calculate crown area as follows:

CA= π x (R_{1x} $R_{2)}$

Where,
CA: crown area (square centimeters)
R_1: Radius from the longest crown diameter (CD1) in centimeters
R_2: Radius from the crown diameter, perpendicular to CD1 (CD2) in centimeters (Conti et al. 2013).

The fresh weight of each stem, branch and leaves was measured on the site using a spring balance. To determine the dry matter content of the woods and leaves of all branches from each stem were taken from thickest to the thinnest to make a composite sample and placed in sealed in plastic bags and transported to the laboratory. In the laboratory, fresh data were dried in the oven and weighted to estimate the water content per species. For stems and leaves dry biomass determination, the oven was set at temperature of 70ºC and 24 hours for leaves whereas for wood parts at 105ºC and 72 hours (Picard et al. 2012). AGB dry biomass per individual species was obtained by subtracting water content from individual fresh mass-weighted in the field. The carbon stock of a single shrub was obtained by multiplying the respective AGB by conversion factor or a default value of 0.5. This value is used when the following situation is happening. The wood density data for Ethiopian plant species is obtained from, the Ministry of the Environment and Climate Change (https://www.google.com). In cases where the wood density for a species was not listed, an average default value of 0.5 was used, as Chave et al. (2005) recommended for trees/shrubs from tropical forests.

Data analysis

R-software was used for data analysis. Data were analyzed using descriptive statistics, linear regression, and Pearson correlation analysis. All of the variables were log-transformed in order to apply linear models. Single and multiple variable allometric equations were developed. Single variable refers to either diameter at the breast height (DBH), height (H), or crown area (CA), while multiple variables refer to the combination of two or three of these factors. Then, the selection of the best fit model was based on the goodness fit statistics (R^2) calculated for the species-specific equation such as adjusted coefficient of determination (R^2 adj), standard error of the mean *(*SE*)*, and Akaki information criterion (AIC).

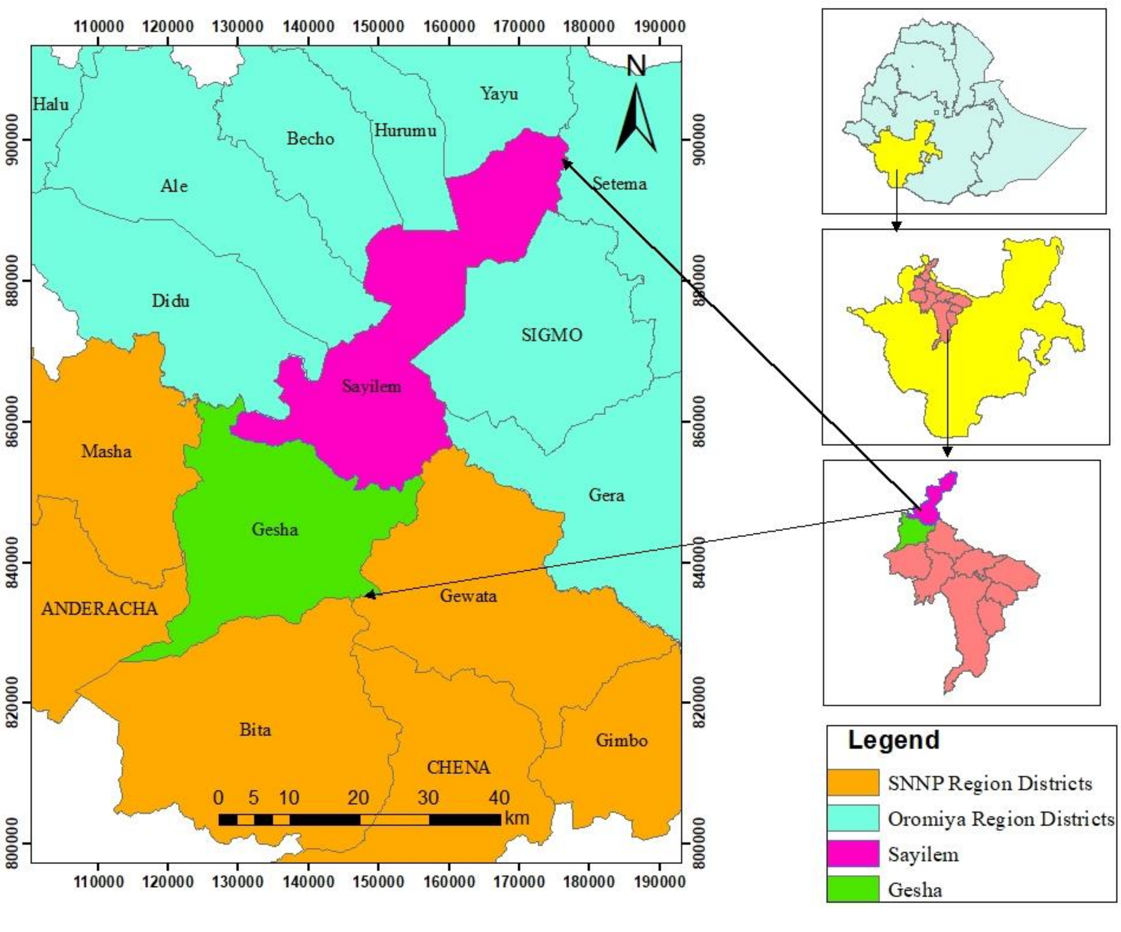

Figure 1. Map of Ethiopia, Oromia and SNNP Region, Kaffa zone, Gesha and Sayilem districts (Addi et al. 2020)

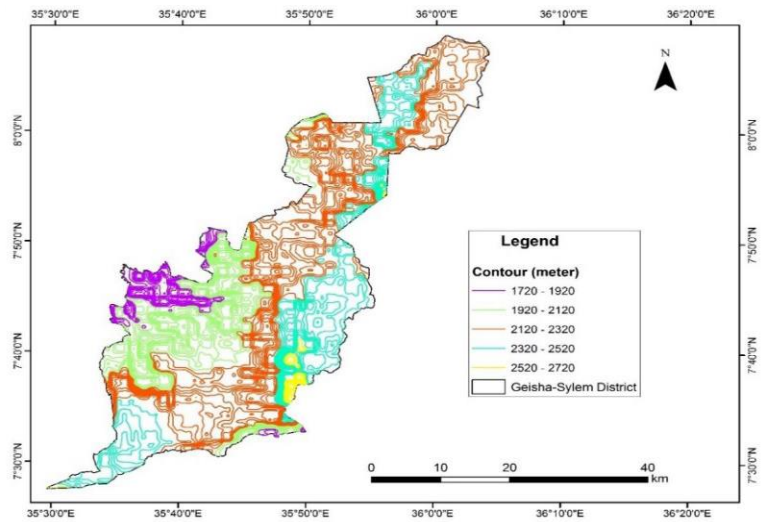

Figure 2. Gesha-Sayilem Digital Elevation model

Table 1. Biomass models used to predict aboveground and components' biomasses of *Galiniera saxifraga* in Gesha-Sayilem forest

Model	Equation
M_1	$\log(AGB) = \beta_1 \log(DBH) + \varepsilon$
M_2	$\log(AGB) = \beta_1 \log(\, height\,) + \varepsilon$
M_3	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \log(height) + \varepsilon$
M_4	$\mathrm{Log}(AGB) = \beta_1 log\, \mathrm{l}(DBH) + \beta_2 \log(CA) + \beta_3 \log(DBH) : \log(CA) + \varepsilon$
M5	Log(AGB)=$\beta_1$log(DBH)+$\beta_2$log(Height)+β_3 $log(CRA)$
M_6	Log(AGB) = $\beta_1$log(Height)+β_2(CRA)

Note: AGB (aboveground biomass), β_1 $(estimated\ parameters)$ BH (diameter at breast height), CRA (crown area), ε $(residual\ error)$

RESULTS AND DISCUSSION

Biomass measured variables

Allometric equations were developed by relating AGB against the predictive variables (DBH, height, and crown area) individually and in combination for *G. saxifraga* plant species. Data of the main variables were generated from direct field measurements. However, data for AGB was calculated from field and laboratory measurements. Descriptive summary for main variables was presented in Table (2).

The aboveground biomass of *G. saxifarga* was positively correlated with the three variables (DBH, height, and crown area). The amount of aboveground biomass was highly affected by diameter at breast height (DBH) (R-squared was (62.02%) followed by crown area (R-squared: 48.45%) while less affected by the total height of the plant (Figure 3).

Pearson correlation of biometric variables to biomass compartments

The person's correlation analysis between aboveground biomass and biometric variables (DBH, height, and crown area) were shown in Table 3. The aboveground biomass was strongly correlated with DBH and it is the most influential factor affecting the biomass of the *G. saxifraga*. Crown area is the second important factor correlated strongly with biomass while height was poorly correlated with aboveground biomass. Furthermore, the analysis of sub-biomass (stem, big branch, small branches + leaves, and aboveground biomass) compartment of *G. saxifraga* showed that the biomass was strongly correlated with DBH in *G. saxifraga* but crown area is poorly correlated and no significant correlation was obtained with height.

The distribution of mean biomass fractions for the *G. saxifraga* showed that on average stem, branch and leaf biomass contributed to 6 and 13 kg of carbon/plant for foliage and wood respectively (Table 4). This indicates that the wood part of *G. saxifraga* stored more carbon than the foliage parts. The majority (68.42%) of the carbon of *G. saxifraga* was found in the stem and branch of the plant. The difference between branch and twig is that branch is a woody part of the tree or shrub arising from the trunk and usually dividing while twig is a small thin branch of a tree or shrubs.

Model selection and validation

This study explored the weight of several models with respect to the three primary biometric variables (DBH, H and CA), for estimating the AGB of *G. saxifraga* in Gesha-Sayilem forest. Selection of allometric equations was employed using statistical model performance. Equations with a higher coefficient of determination (adjusted R^2), lower residual standard error, and Akaike information criterion (AIC) values were found best-fitted. The DBH and crown area were found to be the best fit variables for *G. saxifraga* with the adjusted R^2 value 0.9 and AIC values was 47.37 for estimating the total AGB (Table 5). The coefficient of determination (R^2) tells us the amount of percentage influence by independent variable on the dependent variables. In multiple regressions, adjusted R^2 considers the degrees of freedom it would be used instead of R^2 (Maraseni et al. 2005). Accordingly, model 4 was well performed in all parameter estimates and selected as the best to predict the aboveground biomass of *G. saxifraga* plant species. Allometric equations developed by Kuyah et al. (2012) based on crown area had a good fit with 85 % of the variation in aboveground biomass which was explained by crown area. Similarly, crown area explained a large fraction of the variability in each biomass component, with the greatest variability observed explained in branches. Many authors have been explained that DBH is commonly used in allometric equations to estimate AGB. It can be used either alone or in combination with height, wood density or crown area depending on the nature of plant species (Ketterings et al. 2001; Chave et al. 2005; Kuyah et al. 2012). DBH can be measured easily with high accuracy and explains over 95% of the variability observed in the AGB (Kuyah et al. 2012). On the other hand, crown area could also be used as primary predictor variables, especially for highly branched crown plant species (Sah et al. 2004; Gibbs et al. 2007). The most important predictor of aboveground biomass is usually DBH (Nogueira et al. 2018). On the other hand, Conti et al. (2013) indicated that the crown area and crown shaped variables proved to be the variables with the best performance for both species-specific and multispecies shrubs models. A high proportion of biomass was accumulated in the stem and big branches of *G. saxifraga*. Similarly, Oliveira et al. (2011) study on coffee plants grown in agroforestry indicates that the woody component (stem + branch) accounted for 60-90% of aboveground biomass, the remainder being leaf biomass. The smaller biomass was accumulated in small branches and leaves.

Table 2. Summary of the measured variables and mean biomass of *Galiniera saxifraga* in Gesha and Sayilem forests

Parameter	Mean	Standard deviation	Minimum	Maximum
DBH (cm)	8.00	3.70	1.90	19.10
Height (m)	4.27	1.07	2.00	7.00
Crown area (m^2)	8.00	4.50	1.80	17.50
Aboveground biomass (kg/plant)	19.0	11.80	3.40	44.10

Table 3. Pearson's correlation coefficients between biomass compartments (stem, branches and above ground biomass) and dendrometric variables (diameter, height, and crown area) for *Galiniera saxifraga*

Biomass component	Dendrometric variables		
	DBH (cm)	Height (m)	CRA
Stem	0.69***	0.36ns	0.39ns
Big branch	0.54**	0.34ns	0.33ns
Small branches+ Leaves	0.58***	0.39ns	0.53**
Aboveground biomass	0.72***	0.62***	0.41*

Note: ns not significant, DBH diameter at breast height, CA Crown area.* $p \leq 0.05$; ** $p \leq 0.001$;***$p \leq 0.001$

Table 4. Summary statistics of dry matter (kg/plant) of total aboveground biomass components and C contents of *Galiniera saxifraga* plant samples (n = 30)

Component	Dry matter, kg/plant	Minimum	Maximum	Std. Deviation	Carbon kg/plant	% C
Foliage (leaf + twigs)	6	2.87	24.6	4.01	3	31.58
Wood (stem + branch)	13	7.27	23.44	3.87	6.5	68.42
Total aboveground biomass	19	10.14	48.04	7.88	9.5	100

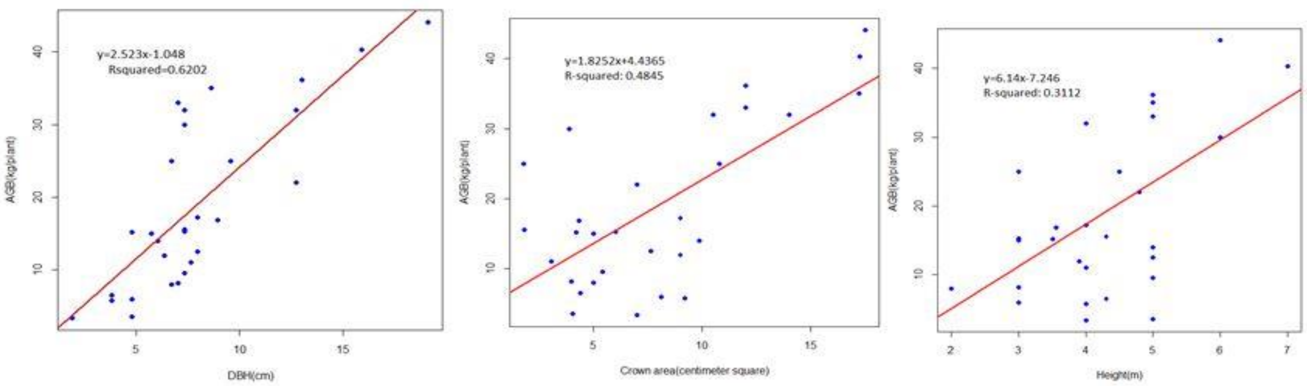

Figure 3. Effect of DBH, crown area, and plant height on the aboveground biomass of *Galiniera saxifraga*

Table 5. Allometric equations and goodness of fit performance statistics for estimating aboveground biomass (kg dry matter/plant) of *Galiniera saxifraga* in Gesha-Sayilem forest (N=30).

Model	Model Equation	Parameter Estimates				Model Performance metrics	
		$\hat{\beta}_0$ (std.error)	$\hat{\beta}_1$ (std.error)	$\hat{\beta}_2$ (std.error)	$\hat{\beta}_3$ (std.error)	AIC	$Adj.R^2$
M_1	$\log(AGB) = \beta_1 \log(DBH) + \varepsilon$	-3.26(0.89)**	1.66 (0.269)	-	-	0.48	0.56
M_2	$\log(AGB) = \beta_1 \log(height) + \varepsilon$	-0.109(0.45)	1.67(0.33)***	-	-	52.6	0.49
M_3	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \log(height) + \varepsilon$	-3.29(0.77)	1.21 (0.23)***	1.09(0.225)	-	34	0.49
M_4	$Log(AGB) = \beta_1 log\ l(DBH) + \beta_2 \log(CA) + \beta_3 \log(DBH) : \log(CA) + \varepsilon$		2.56(0.076)***	2.15(0.682)**	-0.54(0.208)*	47.37	0.90
M_5	$Log(AGB) = \beta_1 \log(DBH) + \beta_2 \log(Height) + \beta_3 log(CRA)$	-3.32(0.72)***	1.2125(0.241)***	1.0663(0.30)**	0.027 (0.13)	36.2	0.72
M_6	$Log(AGB) = \beta_1 \log(Height) + \beta_2 (CRA)$	-0.12(0.46)	1.75(0.38)**	-0.059(0.18)	-	54.6	0.47

Note: AGB (aboveground biomass), DBH (diameter at breast height), CRA (crown area), ε (residual error) (Sign. code: * significant at 5%, ** significant at 1% and *** significant at 0.1%), AIC (Akaike Information Criterion), β0, β1, β2 and β3 are the coefficients

In the conclusion, the total aboveground biomass of *G. saxifraga* plants found in Gesha-Sayilem forest was provided averaged 19 kg of carbon per plant, with 68.42% was obtained from wood parts (stem + branches). This indicates that the wood part of *G. saxifraga* stored more carbon than the foliage parts. Each biomass component was found to be strongly correlated with DBH. Biometric variables DBH, and crown area model provided the best fit in *G. saxifraga.* The model developed in this study can be used to estimate forest carbon stocks, identify carbon sequestration capacity and establish carbon trade, and develop management value.

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